Gas Hydrate Tools (Hardware & Software) Development

1st Quarterly Report

Prepared for The National Energy and Technology Center
Under Contract with B&R#:AB0565000

He, George G (PI), Exarhos, Gregory J, Bamberger, Judith A, and Bond, Leonard J (PNNL),
and Wilson, Thomas H (WVU)

March 26, 2002

Introduction

Gas Hydrates are projected to be the transitional energy source from the current fossil fuel economy to the future hydrogen fuel economy. Until recently, the very existence of natural gas hydrates was one of nature's closely held secrets (Max, 2000). Whether or not gas hydrate (particularly methane hydrate) will potentially become a key contributor to meeting the world's energy needs will largely depend on its recoverability, and its potential impacts on global climate change, seafloor stability and commerciality. Quantitative gas hydrate research and data analysis of direct sampling and measurement, a recent phenomenon, is becoming the critical element in transforming gas hydrates potential to a commercial reality.

This research is aimed at investigating the development of new methods, technologies, and tools to facilitate decision making processes related to gas hydrate exploration for both government agencies and industries through quantitative reservoir characterization. Through cooperation with the NETL program management team and participating industries, PNNL focuses on the development of tools to collect and analyze multi-modality data sets for gas hydrate reservoir characterization from micro scale measurement (laboratory), to well logging and monitoring, and to macro scale (including surface and volumetric) imaging (remote sensing). One of the key elements of this research is to analyze velocity, density, and structure characteristics of gas hydrate bearing strata for seismic data interpretation. This project has two components, one for hardware tool development, and the other for software tool development

Software Tool Development

One of the acknowledged challenges in gas hydrate exploration is the collection, processing and interpretation of seismic data set. Based on high-resolution seismic reflection experiments done at the Mackenzie Delta, Hunter (1999) suggested that lenses of high concentrations of gas hydrates do not appear uniform and continuous over a length of 1200 m. Blanking is one of the significant seismic characteristics in gas hydrate zone. The cementation of gas hydrate is thought to reduce the amplitude (strength) of seismic reflections of the strata. The cementation introduces variability to the gas hydrate zone that affects the reflection continuities, and ultimately signal to noise ratio.   During the first quarter, the major effort has focused on basic research that will improve the signal to noise ratio using Comparative Information Theory (CIT) type concept.

Noise Model:

A series of simple models studies were conducted to examine the possibility of detecting an isolated signal in a noisy background of data. The isolated signal event is shown below in Figure 1. This small "signal" 5 samples in duration was imbedded in the noise near sample 43. The noisy traces are shown below (Figure 2). The noise is random Gaussian with mean = 0 and variance =0.25.

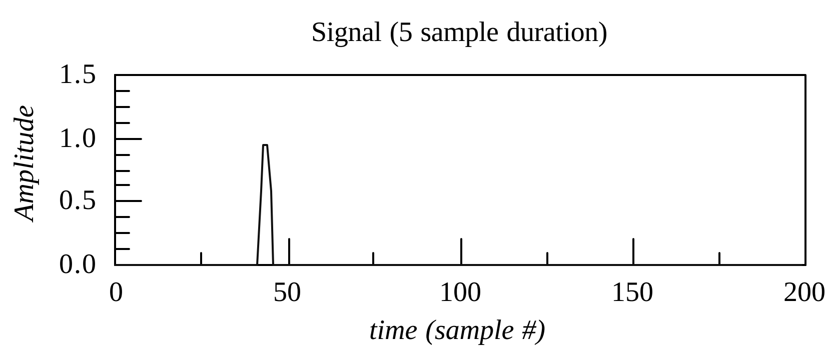

Figure 1: Isolated signal consisting of ½ cycle of a sine wave having 10 sample duration and peak amplitude of 1.

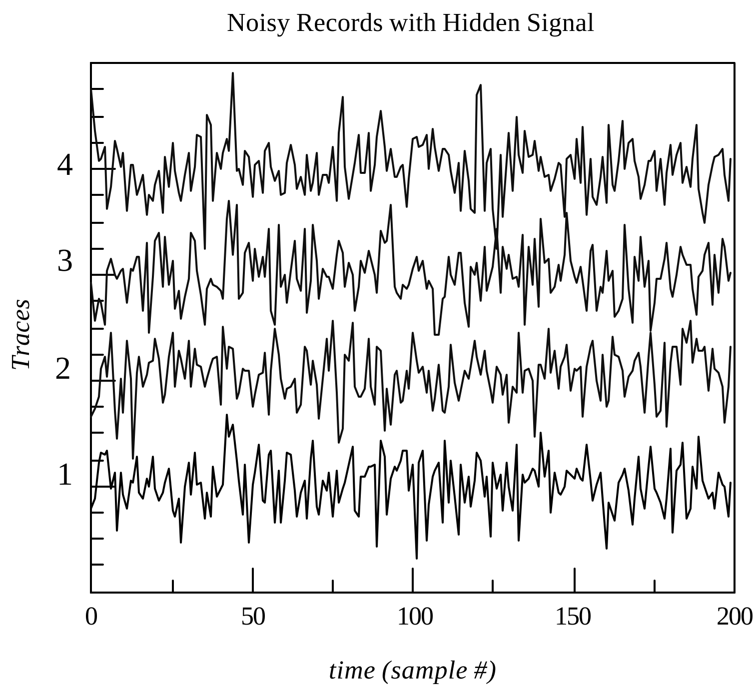

Figure 2: Set of noisy traces used in the study

If we consider this set of traces to be adjacent traces in a common middle point (CMP) gather then traditional signal-to-noise enhancement would be achieved by stacking or summing traces 1 through 4 together. This produces a $\sqrt{N}$ signal-to-noise enhancement, where N is the number of traces in the gather. In this case N = 4 and we expect an increase in S/N of 2. The result shown below in Figure 3 has the desired effect. The event at sample 43 stands out. However, several other possible “signals” also appear in

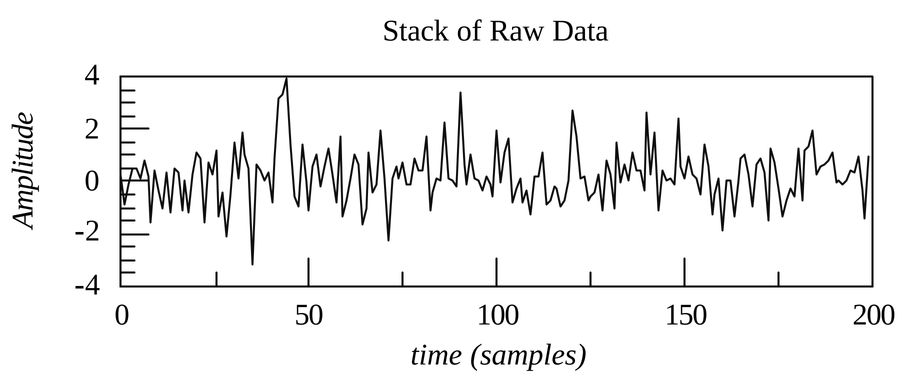

Figure 3: Raw stack of traces 1 through 4 shown in Figure 2.

the stack (see, for example, events near sample 90 and sample 120).

Semblance weighting is also used to enhance signal/noise ratios. Semblance (S) of a function f is defined as

$$S_{k_c} = \frac{\sum_{k=-W/2}^{W/2} \left(\sum_{j=1}^{N} f_{ij} \right)^2}{\sum_{k=-W/2}^{W/2} \sum_{j=1}^{N} \left(f_{ij} \right)^2} \qquad (1)$$

(e.g. Stoffa et al. 1981; Sheriff and Geldart 1983). Semblance is similar to an energy ratio but energy in the j-direction at point $i=k$ is summed over a window of width W centered about k_c for each value of j. In our initial tests we computed semblance for W = 1 and 5 (Figures 4 and 5, respectively).

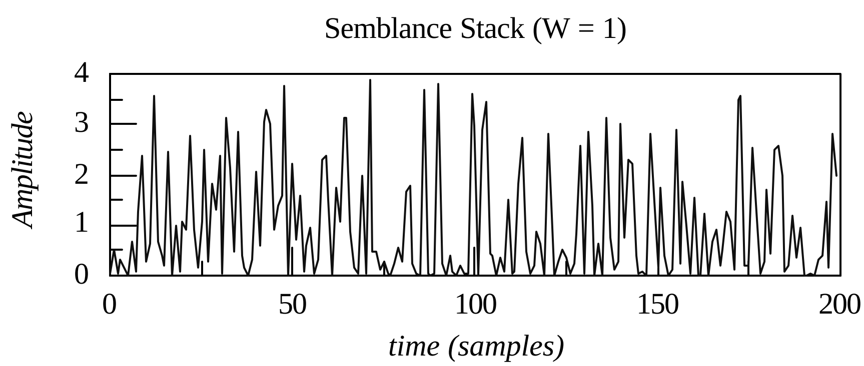

Figure 4: Semblance weighted stack of traces 1 through 4 (Figure 1) for W = 1.

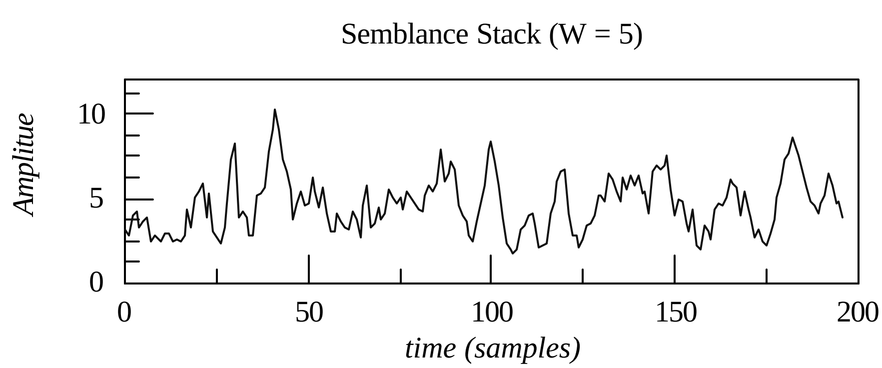

Figure 5: Semblance weighted stack of traces 1 through 4 (Figure 1): W = 5.

Semblance weighting with W=5 (Figure 5) enhances the signal event, but other features derived from the noise also appear; and there is little to distinguish the real signal from the “events” produced by a summation of random noise.

In another test we employed 3-point sums along the length of the trace (through time). Assuming that the noise is basically random, the summation leads to some cancellation (approximately 57% reduction) of random noise relative to the signal.

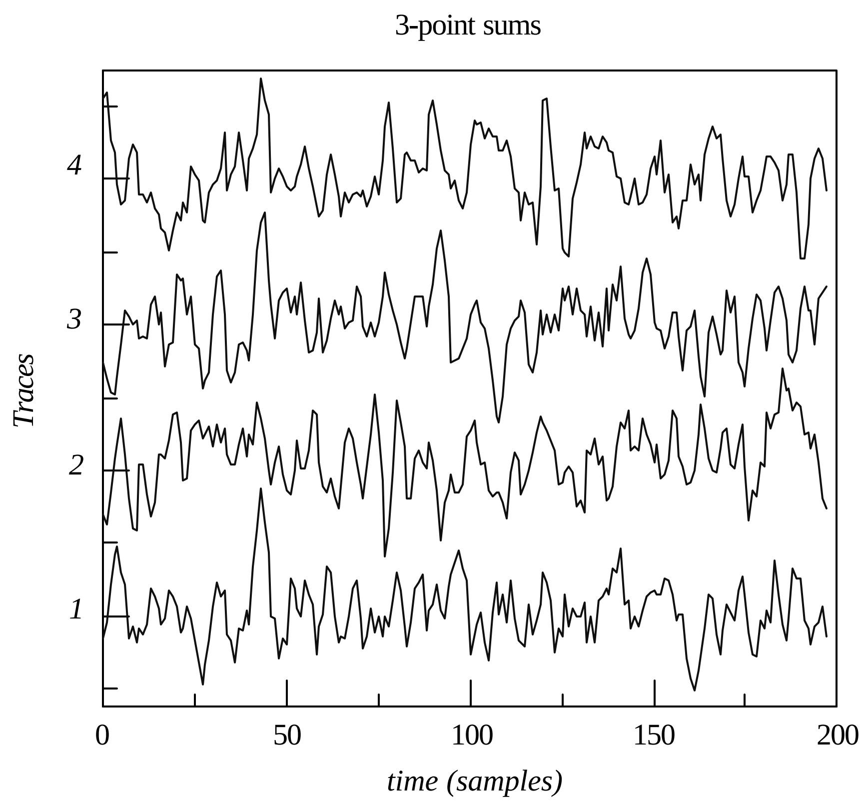

Figure 6: 3 point sums of traces 1 through 4.

The increased signal to noise ratio enhances the signal, but as before spurious events also arise in the data and we clearly cannot argue that the event near 43 samples is signal.

A stack of the three-point sums (Figure 7) yields a result that gives us some confidence in concluding that the event at 43 samples along the time axis is signal. The 4 trace stack of 3-point sums yields better signal to noise ratio than the stack of raw data (Figure 3). The event appearing in the 3-point stack (Figure 7) clearly stands above a background of lower amplitude events. Significant noise remains; the event at approximately 120 samples is a distinctive isolated event, however, it has only 50 % the amplitude of the event at 43 samples and falls within the range of the background events.

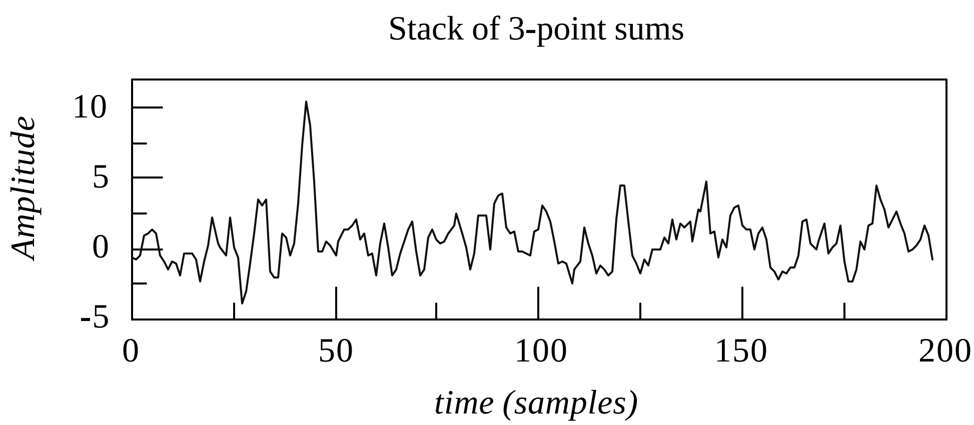

Figure 7: 3-point sums through time (Figure 6) were summed together yielding a 4 trace stack.

We also performed some limited experiments in which ratios of sums were computed. Sums of 5 samples through time were divided by sums of 7 samples (Figure 8).

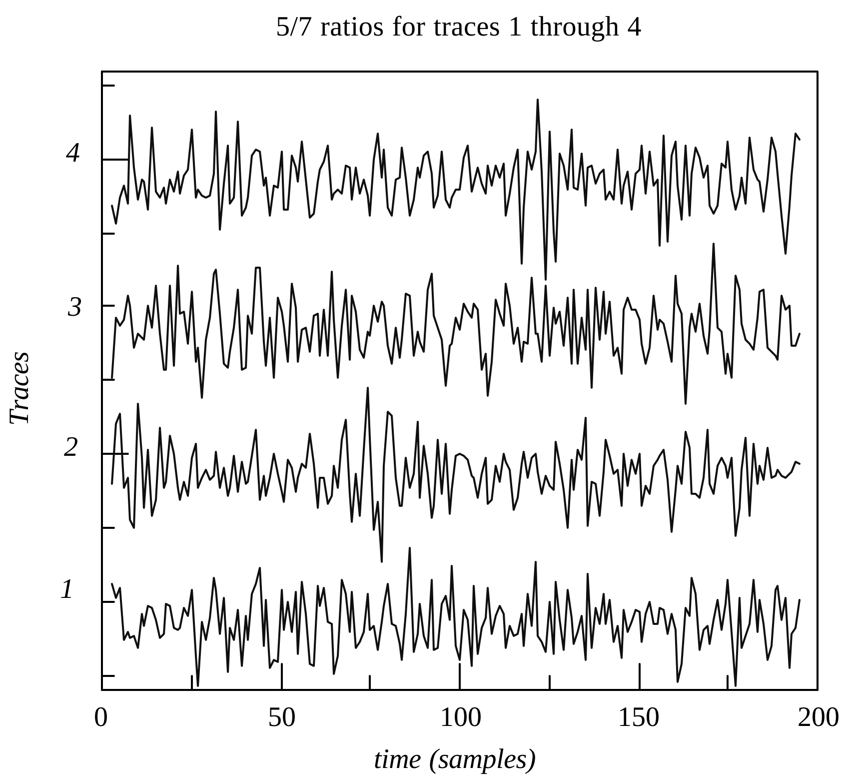

Figure 8: 5point sums through time divided by 7point sums shown for traces 1 through 4.

Edge Enhancement Processing

The results of the edge enhancement process approach developed by Luo et al (2002) are illustrated for Trace 1 of the noisy trace data set (Figure 9) we've been using (see noisy data sets discussed

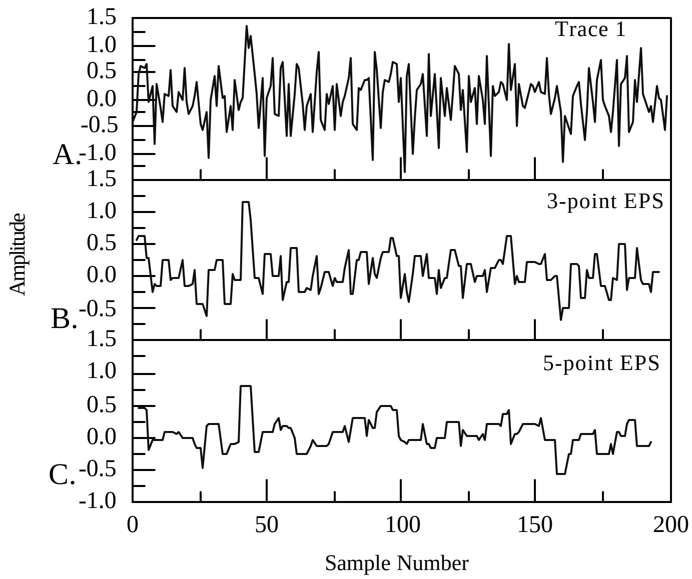

Figure 9: A comparison of the edge-preserving smoother (Luo et al. 2002) to an input trace is shown above. A) The raw input data from noisy-trace 1. B) Output amplitudes based on standard deviations of 3-sample windows. C) Output amplitudes based in standard deviations derived from 5-sample windows.

in previous reports). In this process, the output value is an average. However, output is from cells in the local neighborhood of the output sample, which have the lowest standard deviation in value. These sample averages are least likely to be associated with transitions for signal response to noise response, which will have the highest standard deviation. In addition averages in general should be lower over noise than over signal. Thus, the choice restricts output to averages computed entirely in the noisy background (relatively low averages) or entirely within the signal-dominated region (relatively high averages).

The Single Trace EPS (edge performing smoother) algorithm is developed to simulate the simple average studies parallel to noise modeling. Results of the EPS computation for noisy Trace 1 are shown in Figure 10 for 3- and 5-sample windows.

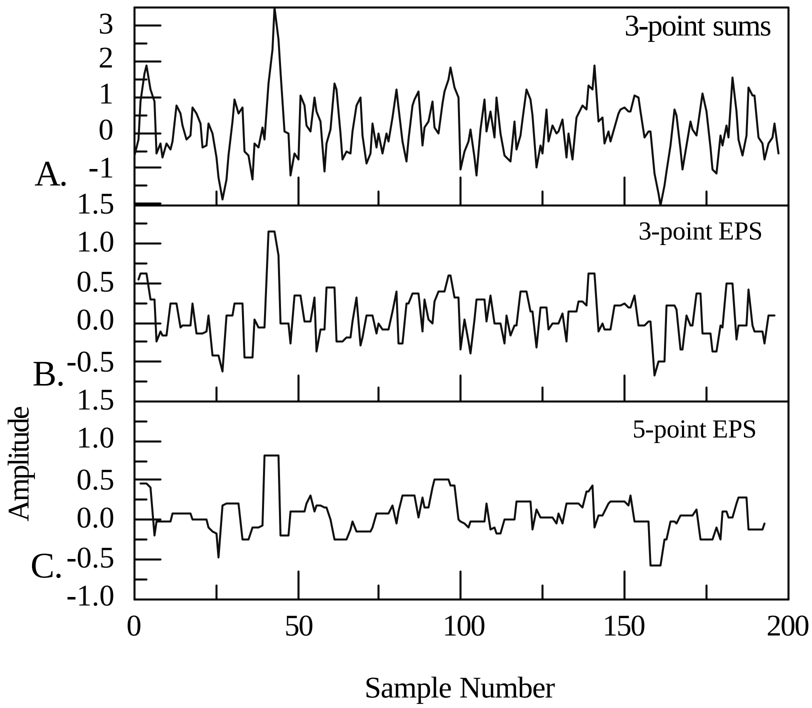

Figure 10: The results of 3-point smoothing are compared to Luo et al.'s (2002) EPS method. The edge preserving smoother provide noticeable, although minor, improvement. EPS significantly reduces the higher frequency variations in the output.

The performance of the edge preserving smoother is compared to results obtained from the 3-point smoother in Figure 10. The comparison reveals that the EPS provides better signal-to-noise enhancement than does the simple 3-point average smoother.

Examination of Figure 10 reveals that signal near samples 42 through 47 stands out somewhat better than that obtained by the simple 3-point sum. The 5-point EPS produces additional smoothing and loss of higher frequency.

Multi-Trace Information Based Comparison (IBC)

The information based comparisons, from initial research applied to the noise model along the length of a single trace, produced significant enhancement of the input trace. However, considerable ambiguity remains. This section shows the results from information based computational approach extended to the multi-trace environment.

The logic of the multi-trace IBC is identical to that explored through the single trace IBC algorithm. The numerator consists of the average value from cells in the local neighborhood of the output sample that have minimum standard deviation in value, while the cell with lowest average absolute value in the neighborhood of the output sample is used as the denominator.

The results of this computational approach are shown in Figure 11. The computations employed investigation of standard deviations from nine 3 by 3 sample cells as the basis for assigning the average value in the numerator. The denominator was chosen from 25 local neighborhood cells as the one having the lowest average absolute value.

Note that the output from our 10 trace data set consists of only 2 traces. The border around the output traces is controlled by the size of the denominator cell. The first output sample lies at the lower right corner of the first 5x5 cell. The last output sample lies at the upper left corner of the last 5x5 cell. In our 10 trace data set, this limits output to traces 5 and 6. The first and last output traces lie 4 traces form the edge of the input trace range. There is also a 4-sample border at the beginning and end of each trace, which is not too noticeable in the figure since the input traces consist of 200 samples per trace.

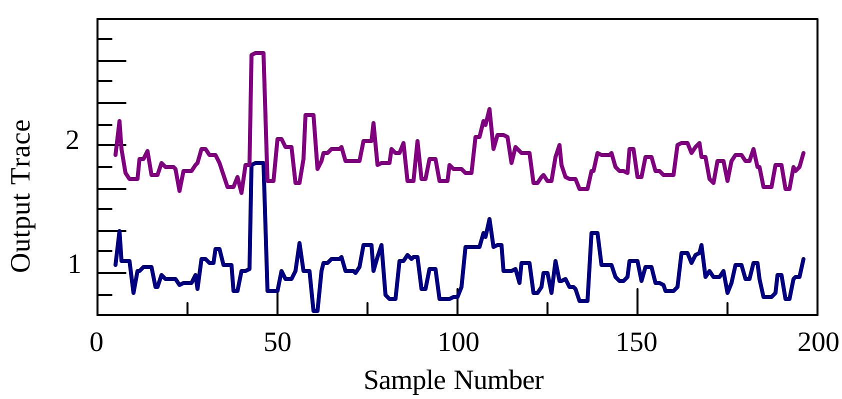

Figure 11: Information based comparison calculated using a 3x3 size numerator and 5x5 size denominator.

The results (Figure 11) reveal significant improvement in the enhancement of signal near samples 42 through 47. The result also compares favorably to those obtained by multi-trace edge-enhancement smoothing and the stacked 3-point sums.

Conclusion For Improving Basic Signal/Noise Ratio Research

We have demonstrated the benefit of integration over time and space domain for enhancing signal/noise ratio for processing seismic data set. The paper by Luo et al. (2002) spurred numerous additional tests to implement their EPS process and compare it to results obtained in our ongoing studies. This evaluation led to development of a new process, which incorporates information assessment in the design of numerator and denominator terms computed in the CIT ratio framework. This computational approach is referred to as an information-based computation or information based comparison (IBC).

As predicted by CIT, the IBC, based on ratio and integration concept, yields promising results. The integration function is not a simple linear transformation in the case of IBC but a statistical function. Future research for this information-based approach should be extended to incorporate energy content into the term selection process. It may also be useful to use local measures of amplitude probability assessment using standard deviations to define local probability model.

Hardware Tool Development

Part I: Raman Spectroscopy Task

Proposed research activities involve development of a portable Raman spectroscopy system that can be used for remote detection of methane clathrates in an ocean environment. Four subtasks have been identified. The first involves the design and construction of a cooled pressure cell with optical ports and gas inlet port that will enable Raman spectra of the clathrate species to be acquired as a function of cell temperature, pressure, solution salinity, and resident pH. The second subtask will use this cell to perform measurements and populate a database consisting of Raman vibrational frequencies of the methane clathrate species and how those frequencies are perturbed by the ambient environment. The third subtask will involve design of a portable spectrometer system with fiber optic interface for performing these measurements in the real world environment. Critical here will be selection of laser excitation source (visible or near IR, pulsed or continuous wave) and spectrometer components to afford adequate resolution of the vibrational features. The fourth subtask will involve performance testing of the portable spectrometer.

The research team for conducting these studies consists of Dr. Gregory J. Exarhos and Dr. Charles F. Windisch, Jr. both from PNNL, and Professor Shiv K. Sharma, Co-director of the Hawaii Institute of Geophysics and Planetology at the University of Hawaii. The research team has developed a design for the pressure cell that will integrate with a small monochromator system already assembled for these studies. A subcontractural agreement with Professor Sharma to pursue work on this progress is scheduled to complete in near term.

The well-log type Raman spectroscopy system design is under way. We will report it in detail in the next monthly report. The development will have three distinctive phases: Phase I: laboratory measurement and signature understanding; Phase II: “Big” instrument design, using the current available high quality equipment in the lab to build a system that can be tested in the field but not compact; Phase III:

the development of a very small compact unit. The key idea for the design is the use of fiber optics for bringing the signals from depth of interests to the surface. The portable spectrometer will be housed above the ground and the laser source (near infrared diode laser or frequency-doubled diode pumped Nd:YAG laser) will be incorporated into the logging devices.

Part II: Real-Time Ultrasonic Characterization of Hydrate Physical Properties during Drilling and Production

We are investigating the ability of ultrasonic sensing to characterize activities associated with exploration and production of gas hydrates in real-time in-situ. The work is underway to obtain samples from drilling site to constrain design parameters. These applications include: 1) characterization of drilling mud both prior and post injection into the well and after it is retrieved from the well, 2) characterization of hydrate laden cores retrieved during drilling operations, and 3) characterization of the physical properties of the gas hydrates during production operations.

Physical characterization is the first step towards exploration of this vast resource. The stability of gas hydrates and in-homogeneity of the hydrate-bearing environment at both micro and macro scale, challenges state-of-the-art characterization technologies. Real-time interrogation during drilling, coring, and production can help quantify the quality, homogeneity, and variability of these activities and provide a baseline when compared to data obtained during evaluation of laboratory samples with which to measure future operations.

Acoustic Interrogation of Drilling Mud

NETL is currently supporting drilling operations at two sites in Canada and nearby in Alaska. This exploration provides the opportunity to evaluate properties of drilling mud being during injection into the borehole during exploration. The mud is characterized prior to entry into the pump by obtaining grab samples whose physical properties are analyzed in the laboratory. After passing through the pump the mud is pressurized to ~ 3500 psig and heated (an undesirable consequence of pump work). The physical properties of the mud are not available for characterization at this location and ultrasound could potentially be used for real-time monitoring at this location. PNNL is developing ultrasonic sensing systems that could potentially be deployed for these measurements; however, at this stage the hardware is not field portable for operation under remote conditions. One simple sensing system, the James V Meter, is packaged for operations in rugged industrial environments. The applicability of using this sensor system to readily measure drilling mud properties is being investigated. Laboratory tests are planned to evaluate a drilling mud simulant through the pipe wall. A list of pertinent process variables that describe this application have been developed and discussed with the staff that will be present during the drilling operations. After additional information is provided it will be used to update the process parameters to be evaluated.

Characterization of Hydrate Samples

There is also a potential to ultrasonically evaluate properties of actual hydrate samples. Another project at PNNL is expecting to receive hydrate samples from recently drilled cores. We will collaborate with this team to try to take non-invasive measurements of the hydrates through the sample container.

Program Management

At the invitation of NETL gas hydrates management team, we participated in two national gas hydrates meetings. This project presented most of the material outlined in this report. The interaction with other research team is very positive. We are very encouraged by the cooperation from BP and others for applying the technologies we are developing. ODP has also encouraged us to work with their academics component to potentially deploy the hardware tools we are developing. We are leveraging heavily from the hardware and tools developed from other projects funded over the years to scope out the best outcome for this project. The team is optimistic about the potential deployment of the developed tools. The next phase of the project is to focus on hardware tool development and to investigate the protocols for integrating the developed tools with industry requirement.

We are very encouraged by the personal communication with NETL project manager about the possibility of additional funding available for developing hardware tools. We will study our approach with the additional data insight gained from the research and interaction during the national gas hydrates meetings. We will make additional request in the next monthly report.

References

Hunter, J.A., R.D. Miller, W.E. Doll, B.J. Carr, R.A. Burns, R.L. Good, D.R. Laflen, and M. Douma, 1999, Feasibility of high resolution P- and S-wave seismic reflection to detect methane hydrate, Geol. Survey of Canada Open File Report #3850, 45 p.

Luo, Y., M., Marhoon, S., Dossary, and A., Alfaraj, 2002, Edge-preserving smoothing and applications: The Leading Edge, v. 21, no. 2, pp. 136-141 & 158.

Max, M.D., 2000, Natural gas hydrate in oceanic and permafrost Environments", Kluwer Academic Publishers, Dordrecht, 415 p.

Sheriff, K.H., L.P. Geldart, 1983, Exploration seismology, Cambridge University Press.

Stoffa, P.L., J. B. Diebold und P. Buhl. 1981, Inversion of data in the $\tau(p)$ plane; Geophys. Res. Lett., 8, pp. 869 - 872.